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KISR Long Atmospheric Boundary Layer Wind Tunnel

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Introduction

Wind tunnel studies are used in many engineering and environmental applications as a key tool to understand problems associated with aerodynamics and transport phenomena. Wind blown sand, sand accumulation on structures, wind load on civil installations and the dispersion of pollutants over industrial and residential areas are examples where wind tunnel simulations can be used to understand and then control related problems.

This paper introduces a new long wind tunnel designed for atmospheric and aeolian studies. Turbulence spires are used to assist the formation of a thick, uniform, steady boundary layer, and initial data on the flow in the test section are presented. A special problem in aeolian tunnels is the sand feeding at the entry, which will often cause instabilities in the momentum budget. Therefore, it is also discussed how arrays of immobile blocks are applied at the upwind edge of the tunnel. It is attempted to design the arrays with an aerodynamic roughness length that will match the dynamic roughness of saltating particles in the test section thereby simulating an infinite upwind fetch.

The KISR Wind Tunnel

The wind tunnel is a low speed, open circuit wind tunnel driven by a centrifugal air fan of 75 kW maximum power at the flow inlet with maximum air speed of 30 m/s, Fig. 1. The intake and the centrifugal fan itself, a wide-angle diffuser, settling chamber, and contraction are all placed in a separate room attached to the main laboratory with the working section. Air can enter the fan from the laboratory or from the outdoor environment through a large gate covered by a filter.

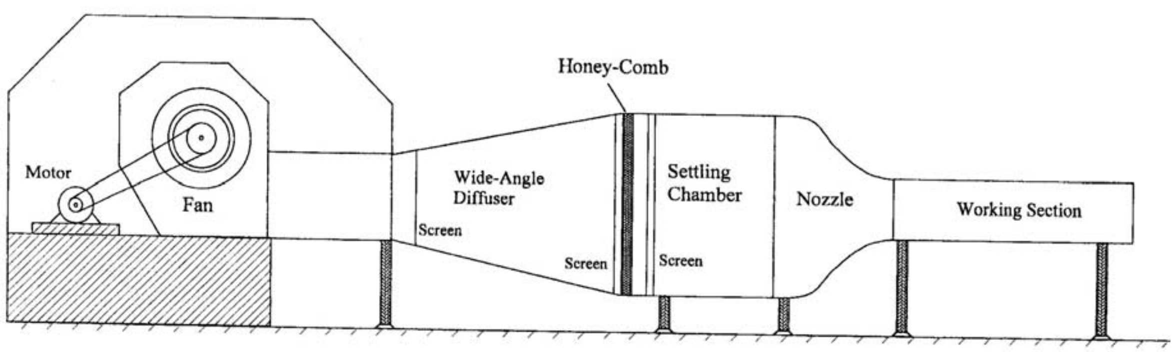

Figure 1: KISR wind tunnel components.

The wide-angle diffuser is connected to the fan via a short, straight transition section with an anti-vibration device to avoid vibrations from the fan to progress to the test section. Screens are placed before the wide-angle diffuser and within the settling chamber where a honeycomb is placed, too. A contraction leads to the working section, which ends in a low angle exit diffuser. The 22 m long working section has a 0.95 m by 1.20 m cross section. There are smooth glass walls on both sides of the tunnel and access is possible through the plywood ceiling and floor. The working area for model studies is situated 15 - 20 m downstream from the entry. In the working area there is also access through the walls via a 0.5 m section of stainless steel sheet fitted into the glass panes. Finally, a turntable in the floor is placed within the working area for modelling of different wind direction.

Experimental set up

The flow in the tunnel was investigated for fan frequency settings of F=6, 11, 20 Hz which correspond to inlet free stream velocities of 2.8 m/s, 6.3 m/s, and 12.5 m/s at the center of the tunnel inlet cross section, P0. Wind speed measurements were made for at three positions in the test section: P0, P1 and P2 at 0.0m, 3.4 m and 17.0 m, respectively. Turbulence was measured using a 1-D hot-wire probe (DANTEC 55P11), while Dwyer Pitot-static tubes connected to an electronic micro-manometer (Flow Master) were used for measuring the mean velocity field. Four levels of boundary layer control scenarios have been tested. Run 1 was made with an empty tunnel primarily to check the wind tunnel specifications. The test is of limited relevance to aeolian conditions since a laminar sub-layer is present above the smooth plywood floor except at high speeds. Therefore only turbulence data measured at P0 will be discussed.

Run 2 was conducted with a thin gravel bed covering the tunnel floor. This bed was chosen because its static roughness is comparable to the dynamic roughness of a saltating sand bed (Rasmussen et al., 1994). The mean flow field at cross sections P1 and P2 was mapped. Measurements were taken along 9 vertical lines with 13 reading points at each line.

In Run 3 the gravel bed was replaced by non-erodible roughness elements (roughness array) for the first 3.5 m of the test section, Fig. 2. The roughness array was designed to match the roughness of the gravel bed, and the flow patterns at P1 and P2 were mapped again.

During Run 4 turbulence spires (Irwin, 1981) were fixed at P0 in front of the roughness array Fig. 2. The spires produce a thick boundary layer, which makes estimation of the surface friction speed and roughness length more reliable and also makes saltation dynamics closer to tits natural state. The flow was also mapped at P1 and P2.

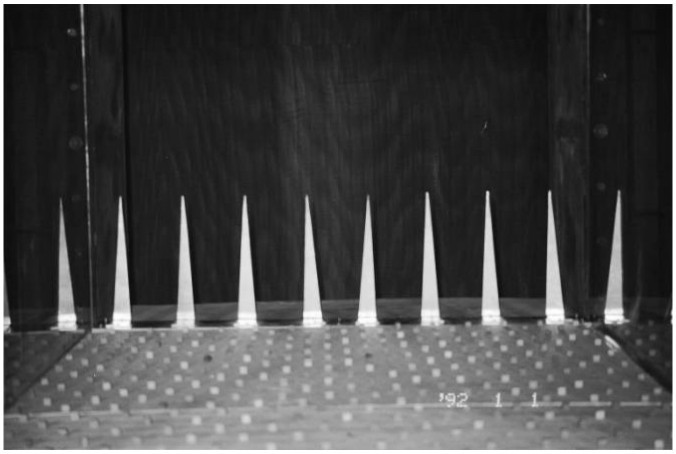

Figure 2: Spires and rough elements at the inlet of the tunnel.

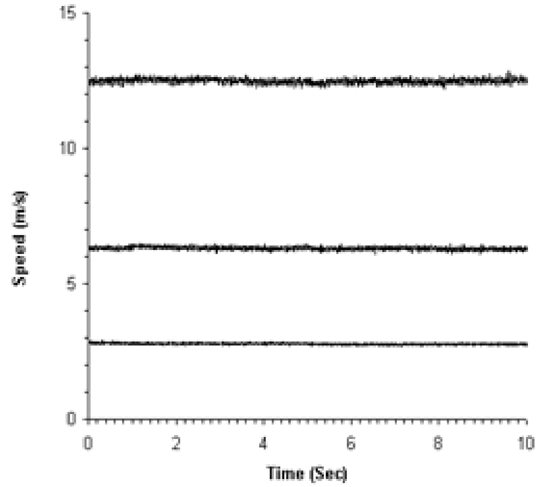

Figure 3: Instantaneous Hot-Wire velocity at P0.

Results and Discussions

The traversing data made during Run 1 (not shown here) indicate that the wind profile is very uniform across the entry and that the wall layer is about 15 mm thick at P0. The turbulence measurements made at P0 at the center of the entry are shown in Fig. 3 for F=6, 11, 20 Hz. The flow is very steady with a coefficient of variation of 1 % or less, which is relatively closed to 0.1 % obtained in many aeronautical tunnels (Bradshaw and Pankhurst, 1963).

For gravel the velocity field at P1 and P2 is shown in Fig. 4a,b and a vertical profile at P1 is depicted in Fig. 5a. In the free stream the flow is fairly uniform, and at P1 the boundary layer is about 10 cm high while at P2 it is about 15 cm high. Along the glass panes the boundary layer thickness increases from less than 10 cm at P1 to about 30 cm at P2.

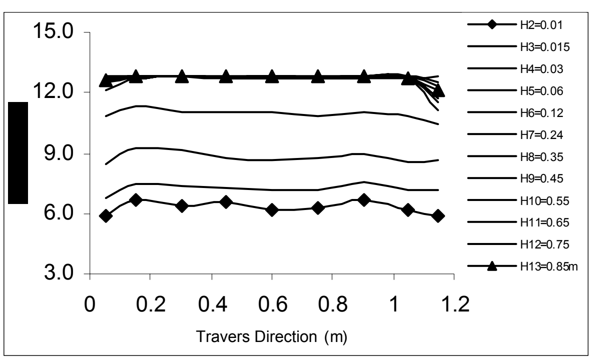

Figure 4a: Crosswise profiles at P1 above the gravel bed for fan setting F=21 Hz.

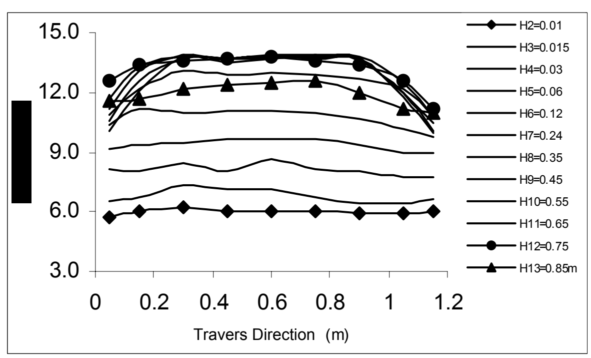

Figure 4b: Crosswise profiles at P2 above the gravel bed for fan setting F=21 Hz.

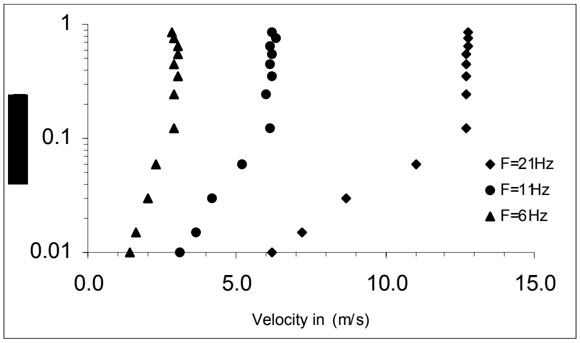

Figure 5a: Wind profiles at P1 above gravel (Run 2) for fan setting F=6, 11, and 21 Hz.

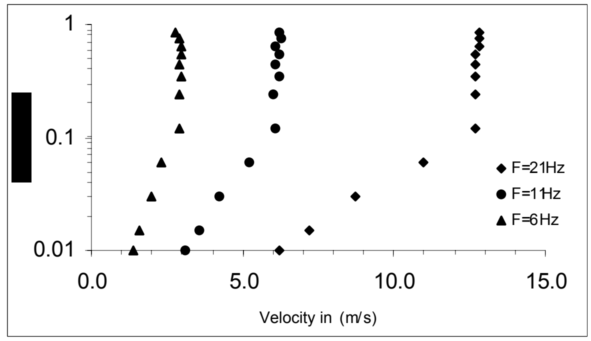

Figure 5b: Wind profiles at P1 above immobile bed (Run 3) for fan setting F=6, 11, and 21 Hz.

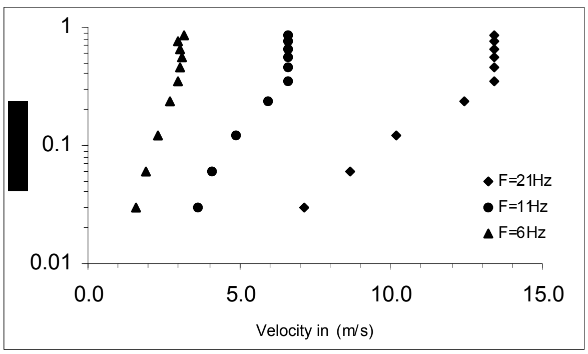

Figure 6a: Wind profiles measured at P1 during Run 4 for fan setting F=6, 11, and 21 Hz.

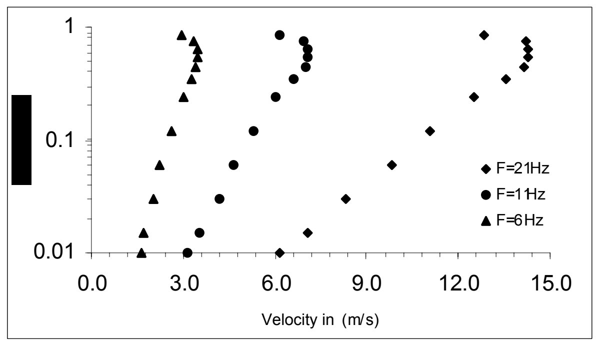

Figure 6b: Wind profiles measured at P2 during Run 4 for fan setting F=6, 11, and 21 Hz.

The vertical profiles recorded above gravel at P1, Fig. 5a, as well as at the downstream end when using the roughness array at the same position P1, Fig. 5b, are fairly similar. This indicates that the flow pattern at the upwind end of the tunnel is reasonably stable and that the design of the roughness array as given by Irwin (1981) works well in the KISR tunnel.

Measurements were repeated with spires added to the previous setting (Run 4). Vertical profiles are shown for different fan speeds at P1, Fig. 6a, and P2, Fig. 6b. These plots show that the boundary layer thickness increases considerably when the turbulence spires are added. At P1 the boundary layer is now about 30 cm high while at P2 is a few centimeters higher. Near the top of the boundary layer the presence of a slight wake (White, 1991) is clearly noticed. The effect of the slight wake is insignificant in the lower part of the boundary layer, say below 10 cm, where good estimates of u* and z0 can be obtained directly from the profile.

Table 1 presents the friction speed and aerodynamic roughness of the gravel bed for different fan speeds during the final run where both roughness arrays and turbulence spires were inserted in the tunnel. It is observed that the friction speeds u^* at P1 is smaller than that at P2 except at the lowest fan speed where they are very closed to each other given the experimental uncertainty. Similarly, the aerodynamic roughness increases as the distance increases from the tunnel entry. Variation of shear stress between up and down stream sections is a common modeling problem especially for long wind tunnels. However, in the KISR wind tunnel a moderately thick boundary layer is created using control measures at the inlet section of the tunnel. The boundary layer grows slowly between P1 and P2. There is a change of about 10% at all fan settings which means that at the central part of the test section, say between 13m and 18m, the net change of u* is less than 5%.

Table1: Friction speed (u^*) and aerodynamic roughness length (z_o) for Run4.

Run 4: gravels + arrays + spires	F = 6 Hz		F = 11 Hz		F = 21 Hz	
	u^* m/s	z_o m	u^* m/s	z_o m	u^* m/s	z_o m
P1 (3.4m from inlet)	0.16	0.00042	0.29	0.00016	0.71	0.00037
P2 (17m from inlet)	0.14	0.00009	0.34	0.00025	0.79	0.00044

Conclusion

Preliminary measurements of the long atmospheric boundary layer wind tunnel established at KISR are presented with various inlet and bed surface settings. Turbulence spires, in addition to gravel bed and rough arrays, show that a good and stable boundary layer can be produced at the test section. In order to control the boundary layer development, different settings of turbulence spires and rough elements will be tested in the next stage and before serious sand drift experiments may take place.

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